

Long-Term, Self-Contained
Chemical Protective Ensemble

(U.S.) Municipal Environmental Research Lab.
Cincinnati, Edison, NJ

Prepared for

Chemical Research and Development Center
Aberdeen Proving Ground, MD

1984



A LONG-TERM, SELF-CONTAINED, CHEMICAL PROTECTIVE ENSEMBLE

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IAG AD-21-F-2-A049

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NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

TECHNICAL REPORT DATA (Please read instructions on the reverse before completing)		
1. REPORT NO. EPA-600/D-84-084	2.	3. RECIPIENT'S ACCESSION NO. PB84-168640
4. TITLE AND SUBTITLE A LONG-TERM, SELF-CONTAINED, CHEMICAL PROTECTIVE ENSEMBLE		5. REPORT DATE 1984
7. AUTHOR(S) Royer, M.D., EPA; Turpin, R.D., EPA; Drúyor, D.D., US Army; Kranz, M. U.S.D. Corp.		6. PERFORMING ORGANIZATION CODE
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army, Chemical Research and Development Center Aberdeen Proving Ground, MD 21010		8. PERFORMING ORGANIZATION REPORT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory -- Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		10. PROGRAM ELEMENT NO. YFD-001
15. SUPPLEMENTARY NOTES Michael D. Royer 201-321-6633 (FTS:340-6633)		11. CONTRACT/GRANT NO. AD-21-F-2-A049
16. ABSTRACT A joint U.S. Environmental Protection Agency (EPA)/Army project is in progress to produce a Long-term (2.5-hr), Self-contained, Chemical Protective Ensemble (LSCPE) with a NIOSH-certified breathing apparatus. The LSCPE provides the wearer with a combination of assets including mobility, air supply duration of 2.5 hours, cooling capacity, and protection from chemical exposure. The LSCPE outergarment is totally encapsulating, has a zipper-closure, and is constructed of chlorinated polyethylene. The "gathered" areas that encircle the waist and knees enable the inside volume of the suit to expand temporarily during normal movements. This temporary expansion prevents the release of pressurization air from inside the outergarment. A pouch in the front of the outergarment contains a heat exchanger and a water-ice mixture. A cooling garment covers the upper body and thighs. A pump, which is mounted in the LSCPE backpack, circulates coolant through the cooling garment and then to the heat exchanger in the outergarment. The backpack contains the LSCPE 2.5 hour closed-circuit breathing apparatus, the body-cooling system pump, a breathing air cooling device, and a pressurization system. The compressed air pressurization system also provides an escape breathing air source.		13. TYPE OF REPORT AND PERIOD COVERED Conference paper, 4/83-9/83
14. SPONSORING AGENCY CODE EPA 600/14		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
19. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS (This Report) UNCLASSIFIED	21. NO. OF PAGES 20
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE

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ABSTRACT

A joint U.S. Environmental Protection Agency (EPA)/Army project is in progress to produce a Long-term (2.5-hr), Self-contained, Chemical Protective Ensemble (LSCPE) with a NIOSH-certified breathing apparatus. The LSCPE provides the wearer with a combination of assets including mobility, air supply duration of 2.5 hours, cooling capacity, and protection from chemical exposure. The LSCPE outergarment is totally encapsulating, has a zipper-closure, and is constructed of chlorinated polyethylene. The "gathered" areas that encircle the waist and knees enable the inside volume of the suit to expand temporarily during normal movements. This temporary expansion prevents the release of pressurization air from inside the outergarment. A pouch in the front of the outergarment contains a heat exchanger and a water-ice mixture. A cooling garment covers the upper body and thighs. A pump, which is mounted in the LSCPE backpack, circulates coolant through the cooling garment and then to the heat exchanger in the outergarment. The backpack contains the LSCPE 2.5 hour closed-circuit breathing apparatus, the body-cooling system pump, a breathing air cooling device, and a pressurization system. The compressed air pressurization system also provides an escape breathing air source.

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) and the U.S. Army are engaged in a joint project to improve an existing prototype chemical protective ensemble, obtain NIOSH certification for the improved ensemble breathing apparatus, and produce five complete, improved ensembles. This paper describes the objectives and status of this work and describes the operating and safety features of the improved ensemble, which is known as the Long-term, Self-contained, Chemical Protective Ensemble (LSCPE).

EPA activities during chemical spill and hazardous waste site responses include environmental damage assessments, on-site consultation to develop appropriate response actions, sampling, and supervision of work by contractors. The Army also conducts a wide range of activities involving chemical munitions and hazardous substances. Because of these operations, a need arose for a totally encapsulating ensemble that would provide:

- (1) A self-contained, long-term service life of approximately 2.5 hours. This service life was viewed as a means for increasing the ratio of the wearer's productive to unproductive work per tank of breathing gas. As the service life increases, the wearer has more time for productive work and can still complete necessary, but unproductive tasks, such as donning, doffing, and decontaminating the outer garment, and walking to and from the work site in the contaminated zone.

- (2) An auxiliary egress breathing system in the event of a primary breathing system failure.

(3) A pressurized outer garment to prevent inward penetration of contaminants through pinholes.

(4) Positive-pressure in the breathing apparatus facepiece during both inhalation and exhalation to decrease the probability of contaminants penetrating through the face/facepiece seal into the wearer's breathing zone.

(5) NIOSH certification of the ensemble breathing apparatus.

When the need for a long-term, self-contained, chemical protective ensemble was identified, existing systems were evaluated and none was available that met all the criteria cited above. The ensemble that came closest to meeting the desired requirements was a prototype system that had been designed and built under a joint Army/U.S. Coast Guard (CG) program. This prototype system satisfied all but the NIOSH-certification criterion. Other modifications to the system were also recommended based upon user comments. Due to the mutual interest of the Army and EPA in continuing the development of the ensemble, an Interagency Agreement (IAG) was initiated, and subsequently, a contract was awarded in April 1983 to USD Corporation of Santa Ana, CA, to modify the Army/CG prototype design, obtain NIOSH certification for the modified breathing apparatus, and deliver five complete ensembles to the Government.

LSCPE IMPROVEMENTS RESULTING FROM CURRENT PROJECT

The major LSCPE improvements that will result from the current project are as follows:

- o NIOSH certification of the LSCPE breathing apparatus - The breathing apparatus of the LSCPE is scheduled to be submitted in February 1984 to NIOSH for testing and certification as described in 30 CFR Part 11. This includes preparation of complete and acceptable drawings, specifications, and quality assurance plans; performance testing of service time, exhalation resistance, inhalation resistance, carbon dioxide and temperature levels of inspired air, low temperature operation, and gasoline vapor permeation of breathing bags; and evaluation of operation and maintenance manuals.
- o Reduction of the weight of the backpack unit by 4.3 kg (9.5 lb) - The weight of the backpack unit was reduced from 19.7 to 15.4 kg (43.3 to 33.8 lb). This weight reduction was required to meet NIOSH requirements and to benefit the wearer. Weight reduction was achieved primarily by utilizing a lighter cooling pump battery and lighter gas cylinders. The cylinders are filament wound aluminum cylinders. The cylinders weigh about half of what steel cylinders would weigh at the 20,700 kPag (3000 psig) service pressure of this unit.
- o Reduction of backpack profile - Rearrangement of the component layout has resulted in a reduction of the backpack profile by 14 cm (5.5 in) from the previous model. The dimensions of the LSCPE backpack are 62 x 36 x 19 cm (25 x 14 x 7.5 in). The smaller profile of the unit improves the balance and maneuverability of the wearer.

- o Backpack components modularized - The backpack components (breathing unit, coolant pump and battery) have been made more readily accessible by modularizing where practical. This modularization will make the backpack easier to maintain and repair than the previous model.
- o Facemask improvements - The facemask is to be improved by re-configuring the directional valve assembly on the facemask to eliminate uneven weight distribution and by re-positioning the nose-cup for better fit.
- o Additional gauges - Two gauges (oxygen and compressed air) will be added in locations that are readily observable by the wearer.

LSCPE PHYSICAL AND OPERATIONAL CHARACTERISTICS ¹(Sandy, 1981)

²(U.S. Divers, 1979)

³(U.S. Divers, 1981)

The LSCPE consists of four major subsystems:

1. A self-contained breathing unit that consists of a primary breathing system, a secondary breathing system, and an automatic mechanism for changing from the primary to the secondary system in the event of primary system failure;
2. An outer garment pressure regulatory system which maintains a positive pressure within a closed outer garment;

3. A cooling system for maintaining body and breathing gas temperatures at acceptable levels, and;
4. A fully encapsulating outergarment.

Self-Contained Breathing Unit

The Primary Breathing System (PBS) (Figure 1.) is a closed-circuit rebreather with a compressed oxygen [20,700 kPag (3000 psig)]¹ source and a carbon dioxide (CO₂) scrubber canister that contains lithium hydroxide (LiOH) sorbent. The PBS has a projected service life of 2.5-hr, based on a 1.7 liters/min (lpm) [0.06 cu. ft. / min. (cfm)] oxygen consumption rate. When the wearer exhales, gas laden with CO₂ passes through the exhalation hose and then through the scrubber canister, which removes the CO₂. Spring-loaded breathing bags both upstream and downstream of the scrubber canister provide a unique dual breathing bag arrangement to decrease exhalation resistance and reduce heat through conduction over the large surface area of the bags. Upon inhalation, the scrubbed gas passes into the inhalation hose, through the facemask check

1. kPag = kilo Pascals, gauge
psig = pounds/ square inch, gauge

valve, and into the user's breathing zone. When pressure in the breathing circuit falls below a pre-set level, the PBS second stage regulator opens and provides additional oxygen (O_2) to the user. When the PBS O_2 cylinder becomes less than one-quarter full, a pressure switch activates a red blinking light on the wearer's facemask to warn of this condition.

The Secondary Breathing System (SBS) is an open-circuit, pressure-demand, compressed air [20,700 kPag (3000 psig)] system. The SBS is a backup for the PBS and provides an alternate source of breathing air should a PBS malfunction occur that causes a loss of O_2 pressure. It is not the role of the SBS to provide routine extension of the service life (2.5-hr) of the PBS. During normal operations, when the PBS warning system signals that only 25% of the PBS O_2 supply is remaining, then the wearer is expected to begin leaving the site. When a critical loss of O_2 pressure occurs in the PBS, the SBS is automatically activated. When the SBS compressed air cylinder decreases to a pressure [13,200 kPag (1920 psig)] at which five minutes of breathing air are left, the wearer is signalled by a beeper. The SBS also serves as the source of suit pressurization air, but this topic will be addressed when the pressurization system is discussed.

The Automatic PBS to SBS Switchover Mechanism (Figure 1) utilizes a gas-operated logic valve to activate the SBS and shut down the PBS O_2 supply if a critical loss of PBS O_2 pressure occurs. The logic valve is connected in parallel with the PBS O_2 line that goes from the PBS regulator to the PBS demand valve. The logic valve is located in series in the SBS circuit and is between the SBS regulator and the SBS inlet into the wearer's breathing zone.

During normal PBS operation, the logic valve in the system allows the PBS O_2 to flow uninterrupted to the user and keeps the SBS off. When the logic valve loses pressure due to the loss of O_2 in the primary loop, an internal spring operates a logic valve piston that activates the SBS and blocks the flow of PBS O_2 . The switchover to the SBS also activates a continuous green light on the facepiece that informs the wearer that the SBS has been activated and that he should begin moving to an area where he can remove the ensemble breathing apparatus and breathe ambient air.

When the switchover from PBS to SBS occurs, the portion of the PBS rebreather circuit that contains the breathing bags and CO_2 scrubber is also shut off by a spring-loaded valve, called the primary breathing loop valve (PBLV). The PBLV is held open during PBS operation by O_2 pressure from the same PBS O_2 line that activates the logic valve. When pressure in that common O_2 line drops, the PBLV closes off the PBS rebreather circuit. Closing off the rebreather circuit during SBS operation is critical since it prevents injury to the wearer that would occur from re-cycling air without replenishing O_2 . When the open-circuit SBS is operating, exhalation air is vented through an exhalation valve on the mask.

Outergarment Pressure Regulatory System (OPRS)

The OPRS (Figure 1) is designed to maintain a pressurized environment [+150 Pag to +200 Pag (+0.6 to +0.8 inches of H_2O (iwg))] inside the outergarment. A slight positive pressure inside the outergarment is a means of preventing penetration of contaminants through pinholes that may occur during use of the outergarment. The suit is pressurized to a maximum of 200 Pa (0.8 iwg) so that mobility and dexterity of movement is maintained. The OPRS consists of a compressed air cylinder, a suit make-up regulator (SMR), alarms, and an outergarment with special pressurization-related features.

Pressurization Air Supply/ Suit Make-up Regulator (SMR)- After the wearer has suited up, the outergarment is pressurized from an external compressed air source through an inflation valve. If a small leak occurs after initial pressurization, the drop in pressure will be sensed by the SMR that is mounted on the outergarment wall, and compressed air will be vented from the SBS air cylinder, through the SMR, and into the suit interior to return the suit pressure to +150 Pag (+0.6 iwg). The SBS compressed air cylinder is initially pressurized to 20,700 kPag (3000 psig). A maximum of 36 % of the SBS compressed air is available for suit pressurization. When the SBS compressed air pressure decreases by 36% (i.e. to 13,200 +/-700 kPag (1920 +/-100 psig)) a pressure sensing switch begins a sequence of operations that automatically shuts off air to the SMR. This prevents additional air from venting into the outergarment and assures that the wearer will always have the remaining compressed air, an estimated breathing supply of five or more minutes, for egress purposes. Also, when SBS pressure reaches 13,200 kPag (1920 psig), a beeper activates to warn the wearer that approximately 60% of the SBS compressed

air is remaining and that pressurization air has been venting from the outergarment. Loss of pressurization air probably means either a hole in the outergarment or an outergarment exhaust valve malfunction. In either case, the beeper indicates that the wearer should leave the contaminated zone to diagnose and correct the problem.

Pressure-Regulating Features of the Outergarment - The outergarment has several features that are unique because of the pressurized nature of the ensemble. As previously mentioned, the outergarment contains an air inflation valve, similar to that on a tire tube, to enable initial pressurization of the suit. In order to sense the difference between internal and external pressure, and provide a rapid response to pressure fluctuations, the SMR is installed in the outergarment wall. The SMR is detachable and re-useable, even if the rest of the outergarment is discarded due to damage or contamination. An exhaust valve, which opens at a pressure of 700 Pag (2.8 iwg), is provided in the outergarment to prevent excessive pressure from ballooning the outergarment. This outergarment exhaust valve is most likely to activate when the wearer is breathing air from the SBS, since the open-circuit SBS vents the exhaust air to the suit interior.

During testing on the previous Army/CG ensemble, it was found that bending or squatting with a ballooned outergarment caused the internal volume of the outergarment to decrease, which raised the internal pressure and caused excessive venting of pressurization air through the exhaust valve. To solve this problem, elastic bands were incorporated into the outergarment to allow suit volume to vary while keeping suit pressure below the level where venting occurs. The elastic bands also reduce ballooning of the outergarment and thus improve the mobility of the wearer.

Cooling System for Maintaining Body and Breathing Gas Temperatures at Acceptable Levels.

The totally encapsulated ensemble wearer is totally isolated from natural cooling via the environment. The combination of metabolically produced heat and that caused by the heat of reaction of exhaled carbon dioxide (CO_2) with LiOH in the breathing apparatus would quickly cause heat stress injury to the user without a positive method of cooling. Therefore, a cooling system is incorporated into the LSCPE to both cool the inhaled breathing air and the user's body.

The cooling system (Figure 2) consists of two major subsystems: (1) an externally accessible, rechargeable, ice-water coolant reservoir located in the chest region of the outer garment and (2) an internal, closed loop that contains water as a heat transfer fluid. A copper-tube heat exchanger transfers heat generated from the wearer's body and breathing air from the internal loop to the external loop ice-water coolant reservoir. The inside of the copper tube is contacted by the water of the internal loop and the outside of the copper-tube heat exchanger is immersed in the external ice-water cooling reservoir. Internal loop water is cooled as it passes through the copper-tube heat exchanger, then it enters the internal loop reservoir. A battery-powered pump forces the water from the internal loop reservoir through a heat exchanger that surrounds the inlet air hose on the breathing system. Cooling the breathing air is required because the heat of adsorption of CO_2 by LiOH from the recycled air, plus the metabolic heat in the exhaled air can combine to raise breathing gas temperatures in a rebreather to intolerable levels. After passing through the breathing air heat exchanger, the cooling water flows through the interstices inside the panels of the cooling garment. The cooling garment panels cover the wearer's thighs and torso. The wearer can turn the entire cooling system off and on or he can utilize a bypass

control valve to limit flow to the body cooling garment. After passing through the body cooling garment, the internal loop water flows back to the copper-tube heat exchanger where it is re-cooled.

Army tests on an earlier prototype rebreather revealed that one charge of ice-water in the outer loop coolant reservoir provides satisfactory cooling for 30-45 minutes. It is therefore expected that the external ice-water reservoir will require re-charging approximately 3 to 5 times during a 2.5-hr work cycle. The external ice-water pouch is provided with a tube to allow convenient drainage of the spent ice-water mixture. Since the external ice-water pouch is accessible without opening the outer garment to the environment, the recharging can be done in a contaminated area.

Fully Encapsulating Outergarment Physical Configuration

The LSCPE outergarment (Figure 3) has previously been discussed with regard to its role in the pressurization and cooling systems. The outergarment is constructed primarily of chlorinated polyethylene (CPE). The seams, internal boots, and gloves are all heat-sealed into the outergarment. The visor is clear polycarbonate. The final visor configuration will probably have a wider field of view than shown in Figure 3. The closure, located on the back of the outergarment, is a zipper on the inside and a gas-tight CPE interlocking closure on the outside.

CONCLUSIONS

The LSCPE is an attempt to upgrade the safety and operational characteristics of self-contained, totally encapsulating ensembles for use by EPA and Army personnel at chemical spill and hazardous waste site operations or for other activities where totally encapsulating ensembles are required. The LSCPE is distinguished from other totally encapsulating ensembles by the combination of attributes that it offers. The LSCPE provides a novel breathing system combination that provides primary and backup SCBA's with appropriate warning systems, a unique pressurization system to prevent penetration of contaminants, and a cooling system that addresses both body and breathing air cooling and permits coolant replenishment in contaminated areas. Furthermore, the outer garment is an integral part of the breathing, cooling and pressurization systems that it encloses. Delivery of 5 LSCPE's with NIOSH-certified breathing apparatus is scheduled for April 1984.

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ACKNOWLEDGMENTS

The authors of this paper are pleased to acknowledge the development by the U.S. Coast Guard's Office of Research and Development and the U.S. Army's Chemical Systems Laboratory (CSL) of the prototype upon which the LSCPE is based. The authors also acknowledge the development work on the LSCPE outergarment that was done by the CSL in its Defense Protective Ensemble development program.

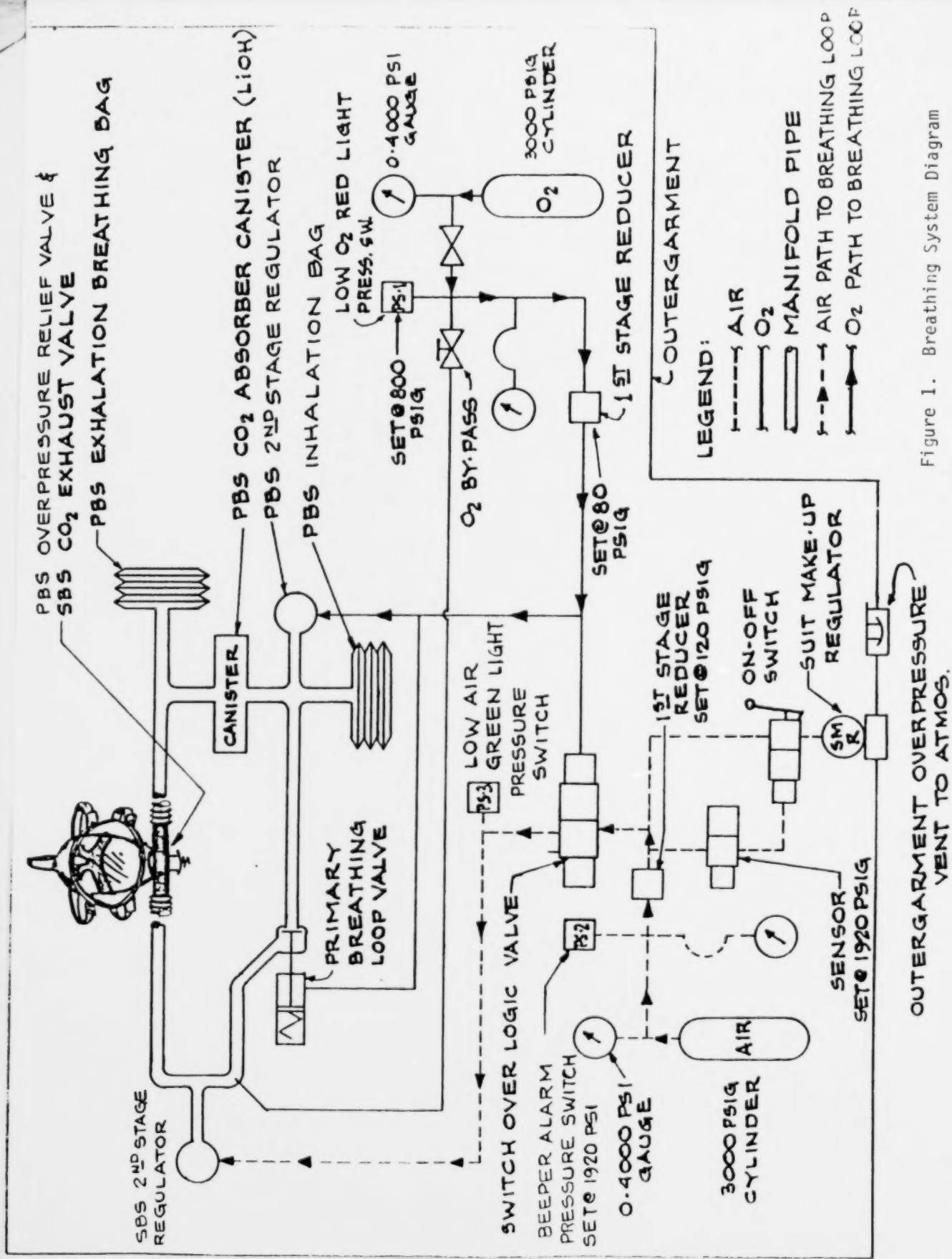


Figure 1. Breathing System Diagram

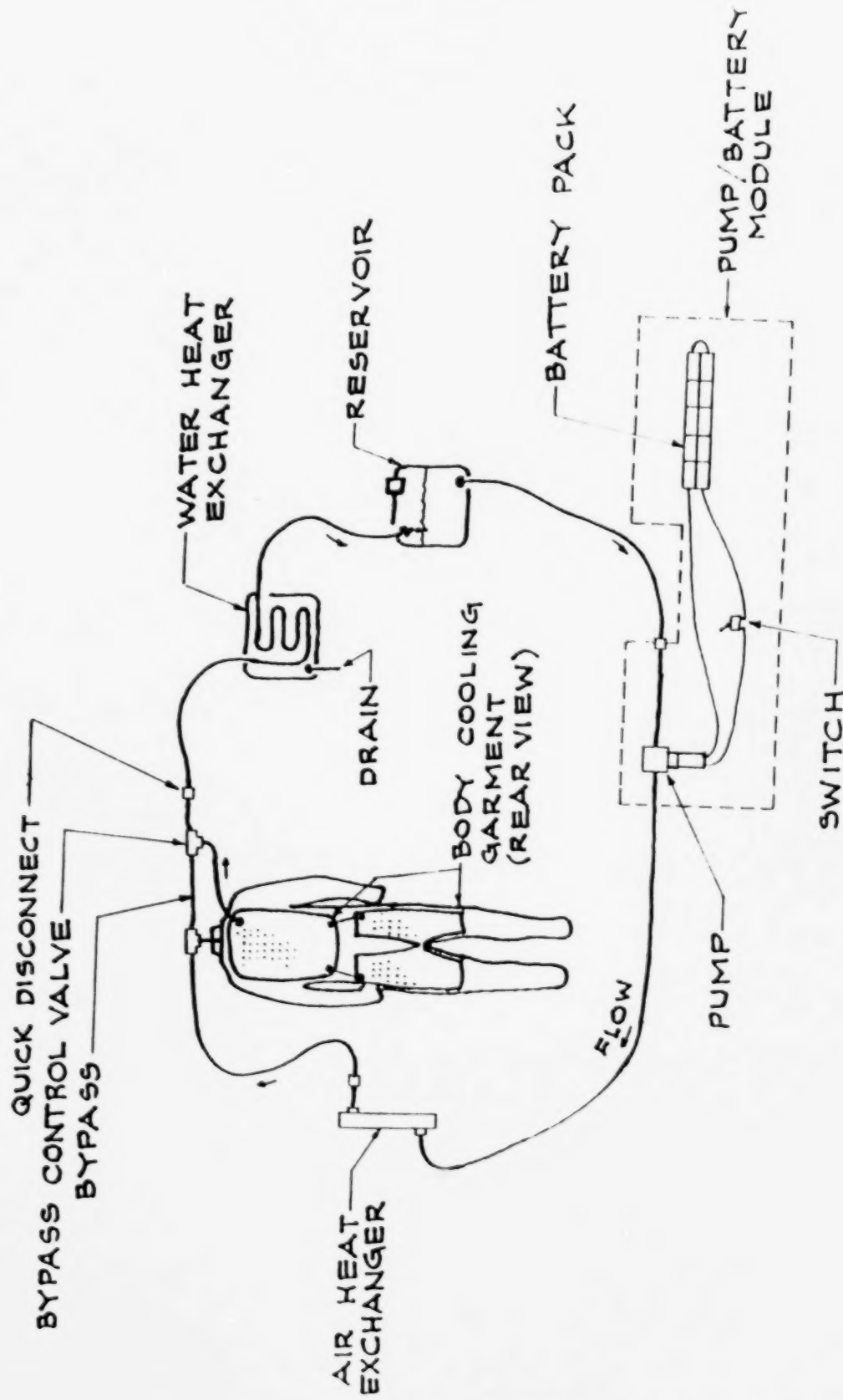


Figure 2. Body and Breathing Air Cooling System.

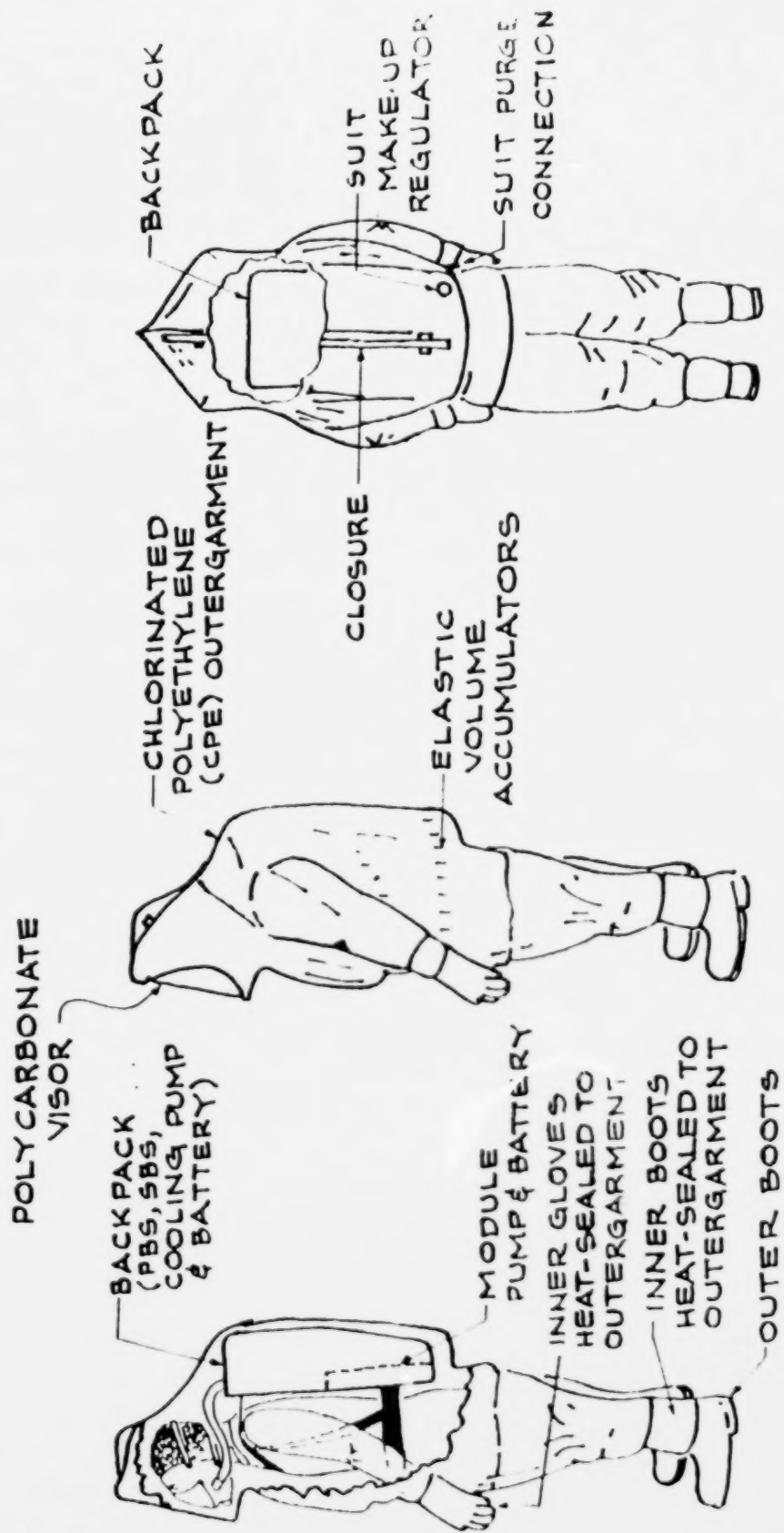


Figure 3. Outergarment